In-Vehicle Software System for Fostering Driver's Attentiveness

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***Abstract*—Traffic accidents due to driver's lack of attention have always been a major concern. Recently, there have been numerous reports of accidents that took place because the drivers were checking their phone or even texting while driving. Current efforts of traffic safety policy makers target the development of strategies that limit mobile phone use while driving. We describe an in-vehicle software system that eases the interaction between the driver and the smartphone. Using our software system, the driver may choose to automatically filter, in an adaptive manner, messages and notifications from third party applications, while driving. Using information from the vehicle sensors, the system identifies potentially dangerous situations and adapts its behavior to limit user distraction. The software development process is based on the principle of separation of concerns. The system complies with Intelligent Environments principles, especially by prioritizing user's safety at all times. Further system developments regard the integration of Augmented Reality visualization and hands-free interaction capabilities.**

Keywords— vehicle safety; context awareness; software systems; software performance.

I. INTRODUCTION

Driver's attention is key to the safety of traffic. It can easily be hindered by distractions such as smartphones, tiredness or engaging in conversation with other passengers. Numerous accidents took place because the driver was involved in activities regarding smartphones. Statistics regarding the number and severity of traffic accidents that involve the use of mobile phones for texting are worrisome [1], [2]. For example, a tragic accident with a Romanian registered minibus took place near Budapest resulting in nine deaths [3]. The driver was streaming live and he did not notice a truck coming towards him and he missed the lane ending signs.

Until recently, Romanian legislation prohibited the act of talking on the mobile phone, with the exception of drivers that use hands-free devices. However, accidents that involve the use of smart phones were still being reported [4]. In August 2019, legislation was reformulated as to include the interdiction to hand hold or use hands to manipulate a smart phone or any mobile device that displays or sends written text messages, photographs or video footage [5].

We identified the need for a system that assists the driver by adaptive managing and filtering events, such as third-party notifications, from the driver's smartphone. Adaptive filtering of the notifications launched by the smartphone takes place according to the preferences of the driver and the traffic conditions perceived by the sensors integrated in the phone. Thus, the main purpose of our system is to help the driver to manage information of interest without using a mobile device (e.g. tablet or smart phone) by hand.

We identified the need for a system that assists the driver by adaptive managing and filtering events, such as third-party notifications, from the driver's smartphone. The role of the system is to help acquire a safe driving behavior. Our in-vehicle system fits the landscape of a smart car – an instance of an Intelligent Environment (IE). Thus, it should adhere to the principles mentioned in [6], such as: (P3) "to deliver help according to the needs and preferences of those which is helping"; (P4) "to achieve its goals without demanding from the user/s technical knowledge to benefit from its help"; (P6) "to prioritize safety of the user/s at all times"; (P8) "to be able to operate without forcing changes on the look and feel of the environment or on the normal routines of the environment inhabitants".

In the following, we present the analysis, design and implementation of an intelligent in-vehicle system - IV-SFDA (In-Vehicle Software for Fostering Driver's Attentiveness). The purpose of the system is to ease the interaction of the user (i.e., the driver) with the mobile phone, while complying with IE principles listed above. The system was designed using the principle of separation of concerns [7]. A concern in information system engineering is a care related to a problem from the real world of one or more stakeholders involved in the construction or evolution of an information system in its natural environment [8].

The system was designed and developed in the context of the research project "Efficient communications based on smart devices for in-car Augmented Reality interactive applications" (see the Acknowledgment section). The project addresses the issue of in-vehicle augmented reality system development,

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focusing on the interaction between intelligent devices and in-vehicle systems. IV-SFDA aims to provide context-sensitive information to drivers, whilst requiring minimal interactions with the human during driving.

The rest of the paper is organized as follows. The next subsections present the motivation behind our work and a review of in-vehicle systems oriented towards traffic safety. The section "Proposal of an in-vehicle software system" describes the functional and non-functional requirements for the proposed system. The software analysis, the architectural design and implementation details are presented in the same section. Empirical validation of the proposed system is described in the subsection "Experimental results" with respect to performance and usability evaluation. The final subsection "Conclusion" outlines the conclusions of the paper and sketches directions for further development.

A. Motivation

Numerous articles tackle the issue of quantifying the degree of distraction involved by smartphone use, by empirical testing or by means of complex analytical procedures. A model that predicts total eyes-off-road time as a measure of distraction, using a regression model built upon empirically obtained estimations in real and simulated environments and the age of the participants, is discussed in [9]. Mobile phone traffic volume is associated to road crash fatalities in large urban areas, as reported by a thorough study involving seven Italian metropolitan areas [10].

Driver's addiction towards cell phone use is evaluated according to the Theory of Planned Behavior in [11]. The prevalence of mobile phone use was the subject of a study performed over university students in Jeddah, Saudi Arabia. The results reported were shocking: over 90% of the participants were using mobile phones during driving, especially for texting [12]. Similar findings are reported in [13], where approximately 40% of traffic collisions were caused by mobile phone usage. The conclusion to the study notes that there is a high risk of accident regardless of the driver using a hand-held or a hands-free device.

The review [11] identified four phases (manual, visual, audio and cognitive disturbances) in the understanding of the impacts of mobile phone use while driving. The work also analyzed specific driver vulnerabilities according to their psychological profile. The absolute conclusion of [11] sets an agenda for traffic safety policy makers to develop strategies that limit mobile phone use during driving.

Our work comes in line with this aim. We propose a complex system designed to reduce the interaction of the user with the mobile phone, making it as seamless and causing as little distraction as possible by filtering/controlling the flow of phone events (e.g., notifications, incoming phone calls, etc.).

B. State of the Art

Our research is situated in the context of in-vehicle systems. We carried out a survey of the technological breakthroughs of ADAS (Advanced Driver Assistance Systems) and identified key elements that should be considered for such a system, which is defined by the active safety paradigm that enhances prevention in contrast to passive safety which tries to diminish losses after the occurrence of an accident [15]. ADAS are based on various sensors and high-level data interpretation techniques such as computer vision detection of other entities in their surroundings, and on access to communication with the V2X platform that connects the vehicles to everything else [15]. Finally, an in vehicle information system design in accordance to the human centered paradigm provides the user with critical information and manages the interaction between the driver and the on board computer systems.

The reviewed articles tackle specific areas of interest, namely challenges in V2X networks, vision based detection and recognition systems, and methods of consciously and subconsciously providing information to the driver. The influence of usual operating commercial IVIS systems upon crashes is the object of the study in [16], with professional drivers being the main subjects. The usability of two different layouts for an IVIS is investigated in [17].

Most in-vehicle software systems were found too distracting to the user to be allowed to run during driving - these are the results from a study on drivers who were evaluated on four tasks (audio entertainment, calling and dialing, text messaging, and navigation) while the car is running [18]. The workload experienced by the driver depends on the various tasks he/she is involved in and on the modes of interaction. The study showed that calling, dialing and text messaging tasks are more cognitively demanding than navigation task and slightly less cognitively demanding than the audio entertainment task [18].

Various commercial systems that track the driver's level of consciousness or that monitor the objects encountered on the road have been proposed and implemented. Attention Assist [19] from Mercedes-Benz makes a personal profile in the first minutes of driving. Then, during the journey compares it with the data obtained from sensors in order to detect drowsiness signs; it accomplishes this by discriminating between fast driver steering wheel adjustments due to drowsiness and external factors such as road unevenness and lateral wind. Pre-Collision System with Driver Attention Monitor [20] from Lexus monitors the gaze direction of the driver and gives a warning if he/she is looking away from the road when there is an obstacle detected ahead, and in certain conditions automatically initiates braking.

A content analysis of a series of smartphone applications intended to prevent distractions from the mobile phone during driving is presented in [21]. The most common feature for the apps was sending an automatic text message reply to a contact who texts the driver. A major limitation revealed in [21] was that the reviewed apps perform only blocking of specific phone functions (calls or text messages). Drivers may not comply with using such apps and may prefer apps that manage the entire workload of the phone while driving.

The IV-SFDA architecture presented in our paper comes to help fill this gap, by providing an adaptive filtering of smartphone events that may distract the attention of the driver.

II. Proposal of an In-Vehicle Software System

In order to foster the driver's attentiveness to the driving task, we propose a software system – IV-SFDA – that allows the driver to manage the information of interest, without using a mobile device by hand. The current system encapsulates the subsystem ANOTIVE we proposed in [22] and refines it further. Using IV-SFDA, the driver may also opt to receive messages that contain information regarding the weather (e.g. temperature, visibility, icon, wind speed and humidity) and technical information about the current state of the vehicle. Also, the driver may choose to be informed of or to block notifications received from third party applications (e.g., Facebook, Gmail, WhatsApp) or any other notification automatically received by his mobile device (e.g. automatic updates for installed software). The user classifies notifications and calls into categories, depending on their profile: regular notifications (that are allowed under normal driving conditions), and high-risk notifications (that are to be allowed even under special driving conditions) [22]. The system switches between contexts automatically, according to the current driving conditions. The driving context is determined by IV-SFDA using data received from the GPS system, the accelerometer of the smartphone and the OBDII component (Fig. 1).

The OBDII device retrieves detailed information from the vehicle by means of a Bluetooth interface. The retrieved data includes: the vehicle identification number, the number of rotations per minute of the engine, the vehicle speed, the coolant temperature and the oil temperature, the fuel level, the voltage at the battery terminals. When a certain parameter approaches its safety threshold, the system is notified and a specific notification is sent to the driver by means of the notifications subsystem.

Fig. 1. The interface of the OBDII subsystem of IV-SFDA.

The system adapts its behavior according to the current state of the car and to the driver's actions. This way, the driver is notified only with information that is important to him, his attention being distracted as little as possible from his driving activity. In the current prototype, the data is received by the mobile device (e.g. tablet or smart phone) and sent to a small, lightweight device, called Head's Up Display (shortly, HUD) which displays a graphical representation of the data. This device sits on the dashboard and projects information onto a car's windshield (see Fig. 2). As part of the bigger project, an Augmented Reality in-vehicle visualization system is currently under development. It will enable the event notifications to be projected directed on the windshield. .

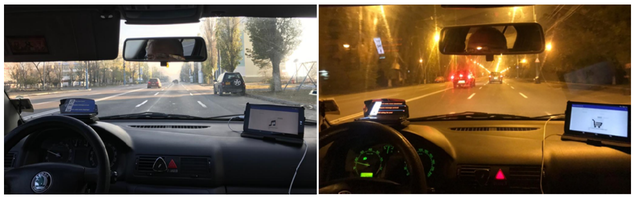

Fig. 2. Running the system on a tablet/phone and viewing the graphical representation of the incoming data on HUD during daytime and at night.

In IV-SFDA, all the information circulated in the system between the producers of information (such as the ANOTIVE subsystem, the weather component, or the OBDII component) and the consumers is stored in raw format, as time indexed collections, in a MongoDB database. Subsequently, this data may be processed through specific queries in order to extract meaningful information

A. *Concern Oriented Software Analysis of IV-SFDA*

In order to identify the functionalities of the software system, we first identified the software actors of our system and their concerns [8] [22]. The software actors for the system are the driver, the co-driver, the phone's GPS system, the accelerometer, the OBDII subsystem, the mail service, the time, and all other third party applications that run on the driver's phone and send notifications.

Human actors have concerns with respect to using the system. We use the concept of the stakeholder's concern as a "problem-originated care of one or more stakeholders involved in the construction or evolution of an information system in its natural environment" [8]. For example, the main concern of the driver during driving is to drive the car while avoiding accidents. From this concern, we infer other concerns that depend on it. Also, other resources that can obstruct the concern from being solved are identified at this point.

In case the driver's mobile phone is turned on and it is placed in the car, other concerns may appear that depend on the first one, such as the concern of being disturbed by unimportant notifications (e.g. received from third party applications, such as Facebook, Gmail, WhatsApp, or any other notification automatically received by his mobile phone, such as automatic updates for installed software) [22].

TABLE I. High Level Specification of a Concern

Concern	The care to not be disturbed by the third-party applications during the driving activity

Problem	*Hypothesis: Driving started and mobile phone works* Conclusion: How can my mobile phone be set up to automatically prevent unwanted notifications from Facebook and WhatsApp during the driving activity?
Stakeholders: Driver, Co-driver	

A concern is *solved* if the participant's care is satisfied, while also dealing with the problem of the concern. In order to solve a concern, some action(s) is performed by one or more stakeholders [8]. Thus, the concern is usually regarded as the source of actions undertaken by stakeholders.

B. Architectural Design of IV-SFDA

IV-SFDA contains three subsystems, as in Figure 3: VisualInformationProducer, VisualInformationConsumer, and Server. The first two subsystems contain components (depicted as UML packages) which play the roles of producer and consumer of information. The VisualInformationProducer app consists of three types of data producers at this moment. The components are mentioned in Fig. 3.

Our system is built on top of Euphoria (Event-based Unified Platform for HeteRogeneous and Asynchronous Interactions) [23]. Euphoria is "natively supported by a wide variety of connected devices, such as PCs, tablets and smart phones, smart watches". The Euphoria web server is part of an event-driven platform that involves production, transmission, detection, and consumption of device- and environment-specific events, using web protocols and technologies (e.g. HTTP, WebSockets, node.js, JSON). In this framework, an event is considered to be triggered by a change in the state of any input device (e.g. environmental motion sensors, smart mobile devices and wearable, etc.). Alternatively, an event may be produced by a software service that is relevant to the environment [23].

Euphoria manages information packed in JSON messages. A message consists of a header with metadata (i.e., the type of event and the name of the device or application that produced the event) and a body that contains information about the event produced.

The PersistenceComponent contains two software components, implemented in node.js [24]:

- MongoLogger allows raw data traffic between producers, via Euphoria, to the MongoDB data warehouse.
- MongoReader allows the traffic of raw data from the data warehouse to consumers who have requested such data.

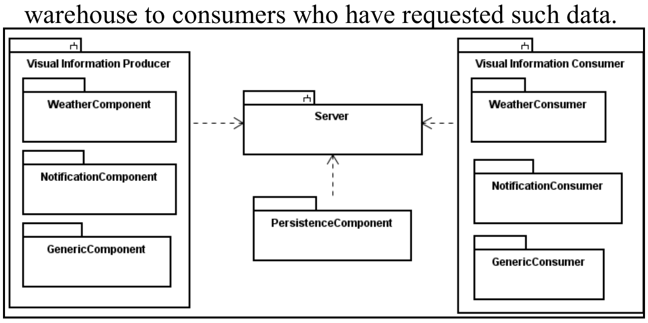

Fig. 3. The subsystems of the IV-SFDA system

Behaviorally, MongoReader is described in the sequence diagram in Fig. 4. The raw data fetched from the database is processed by each consumer, in a specific manner. The MongoLogger behaves similarly.

C. Experimental results

The empirical evaluation of the system has two facets. First, we were interested in evaluating performance criteria for the usage of our system. Next, we tackled usability evaluation. We conducted a study, making use of a questionnaire filled by users that made use of the designed system during a car trip.

1) Performance Evaluation of IV-SFDA

Performance evaluation, with respect to response time, was carried out in various experimental settings. We measured the response time taken by processing a message that was sent as triggered by an event in the producer to a consumer, via the server. In this context, we considered messages of various sizes, i.e., 64Bytes, 256B, 1KB, 4KB, and 16KB. We considered 10 producers running simultaneously, each of them sending 100 messages produced by the components of the VisualInformationProducer subsystem, each message one milliseconds apart from the previous message.

The batch of tests used a 64 bits Ubuntu 18.04.1 LTS running on an Intel Core I3 CPU M 370 @ 2.40GHz x 4, 7, 6 GB architecture for the server. The producers and the consumer ran simultaneously on a Huawei MYA-L41 running Android 6.0, with a Quad core 1.4GHz processor and 2GB RAM.

The mean message processing time for the producer and the consumer, with respect to the size of the processed messages are detailed in Table II. In the parentheses, the standard deviations of the processing time are noted. The variances of the message processing time, for the producer and for the consumer respectively, are statistically different (by Levene test, with significance level $\alpha = 0.05$).

We applied the t-test for unequal variances, for each pair of samples (i.e. a pair of samples corresponds to a given message size), with Bonferroni correction (the significance level was adjusted, hence the used value was $\alpha = 0.05/6=0.0083$). Since all p-values were lower than the significance level proposed, we conclude that the mean message processing times are different for the producers and for the consumers.

TABLE II. SUMMARY STATISTICS FOR THE MESSAGE PROCESSING TIMES FOR THE PRODUCER AND THE CONSUMER.

Message Size (Bytes)	Producer Message Processing Time (ms)	Message Consumer Processing Time (ms)	p-value
64	85.097 (0.944)	148.742 (23.878)	1.17E-08
256	85.285 (2.969)	188.306 (43.971)	7.33E-05
1024	91.672 (0,840)	207.429 (55.969)	1.05E-04
4096	92.352 (3.475)	240.543 (28.11)	3.33E-06
16384	94.373 (1,890)	267.938 (30.055)	5.96E-06

[a]. The p-values obtained for the pairwise (unequal variances) t-tests performed to verify whether the message processing times differ for the producers and the consumers.

The Euphoria framework was previously technically evaluated in [23], with respect to several factors (such as

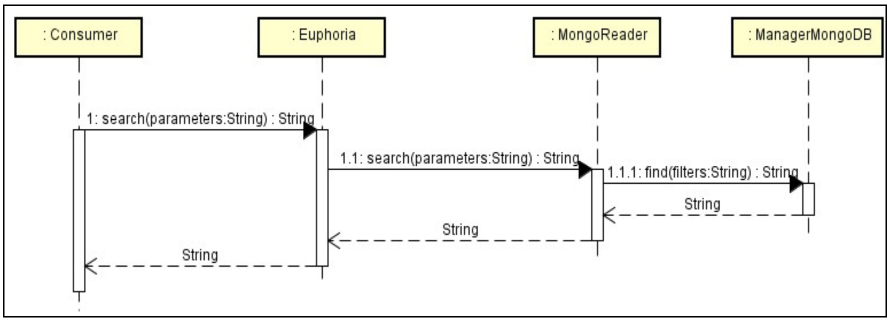

Fig. 4. Sequence diagram that depicts the information flow for the MongoReader component.

message size or device type). The empirical results obtained in testing the IV-SFDA system are in line with results presented in [23]. This confirms that the IV-SFDA integrates well with the Euphoria software architecture [25].

2) Usability Evaluation of IV-SFDA

We were interested in measuring the satisfaction degree of users that are exposed to our system. We conducted a usability survey on a sample of 75 users aged between 19 and 50 years. First, the system was showcased to the selected users. Also, its functionalities were explained. Participants downloaded a copy of the app on their personal mobile Android phone, provided that the Android version installed on the device was greater than 26. Finally, they used the app in during one car trip.

The demographic characteristics of the users are presented in Fig. 5. Most of the users are males, between 19 and 50 years of age. At this stage in our project, the target group for the usability tests was selected among those that presumably have experience using a smart phone. This way, we hoped that the users can objectively evaluate the apps they were asked to review. Inexperienced users may confuse their own difficulties in using a smart phone with shortcomings of the tested apps. We wanted to avoid such an aspect.

The usability test consisted of two parts. The first part consisted of 16 questions with Likert-type rating scale with 5 points answers. The second part contained open-ended questions, meant to gather opinions from the users regarding what they liked or disliked about the system. After the first four generic questions that merely gathered information regarding the profile of the users, question 5 refers to the intellectual effort required for using the system. The answers disagree with the fact that the system require a great deal of intellectual effort. Corroborating this with the answers to question 7 (i.e. "The application requires too much attention from the driver"), we conclude that, at this stage of

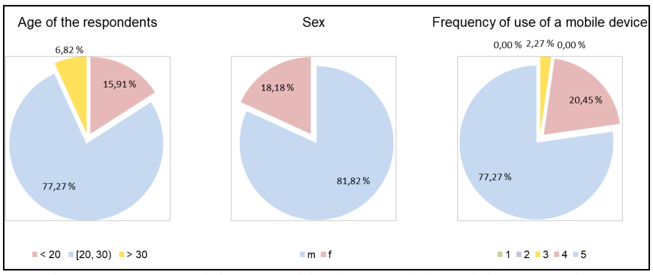

Fig. 5. Summary of demographic characteristics of the respondents involved in the usability testing.

development, the system is easy to use and does not require too much attention or increased intellectual effort (Fig. 6).

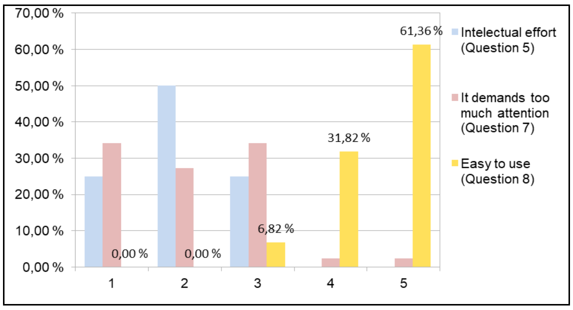

Fig. 6. Overall satisfaction degree of the users.

The readability of information was positively appreciated by the users; 96% of the users responded with 4 or 5 (on a scale of 1 to 5) to question no 9: "I consider the displayed symbols and words were easily readable." The speed with which the application allows access to received information is also appreciated by the users that participated to the survey: 93% of them responded 4 or 5 to question 13: "Using the app, I have fast access to the received information."

We consider that the results of the evaluation survey are encouraging, considering the high level of usability and acceptability appreciated by the users surveyed. Nevertheless, we must consider the influence of the characteristics of the surveyed users: they were mostly men, with a high level of experience with mobile apps. Further work will be devoted to quantifying these influences, if any.

D. *Conclusion*

In this paper, we introduced IV-SFDA, a software system that allows driver to manage in-vehicle smartphone related information, without using a mobile device (e.g. tablet or smart phone) by hand. The system adheres to some key principles of Intelligent Environments [6], such as respecting the needs and preferences of those which it is helping (P3 from [6]) or achieving its goals without special technical knowledge from the part of the user. Also, we stress out that driver's safety is the key concern that our system was built upon; hence principle (P6) is also respected.

Using IV-SFDA, the driver may choose to receive messages that contain information regarding the weather, to receive or block notification received from third party applications. This way, the driver is notified only with information that is important to him, his attention being distracted as little as possible from his driving activity.

The information is received or produced by a mobile device and sent to a smart phone placed on top of a HUD device. This device sits on the dashboard and projects information onto a car's windshield. IV-SFDA adapts to the driving context that is determined by our system using data received from the GPS system, the accelerometer of the driver's smartphone placed in car and the sensors of the vehicle, by means of an OBDII interface. The usability of the system was tested on a sample of 75 users.

We identified several future implementation directions that use the producer/consumer modules developed during the test phase of the project. For example, with respect to the display of information, our main interest is to attain high visibility, regardless of the environmental conditions. An AR visualization system is under development, in order to tackle this issue. Future work also involves integration of gesture and voice based hands-free interaction in the system, in order to tackle driving related events, other than those involving the user's phone.

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